REPORT FROM NEUTRINO FRONTIER

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SNOWMASS COMMUNITY PLANNING MEETING

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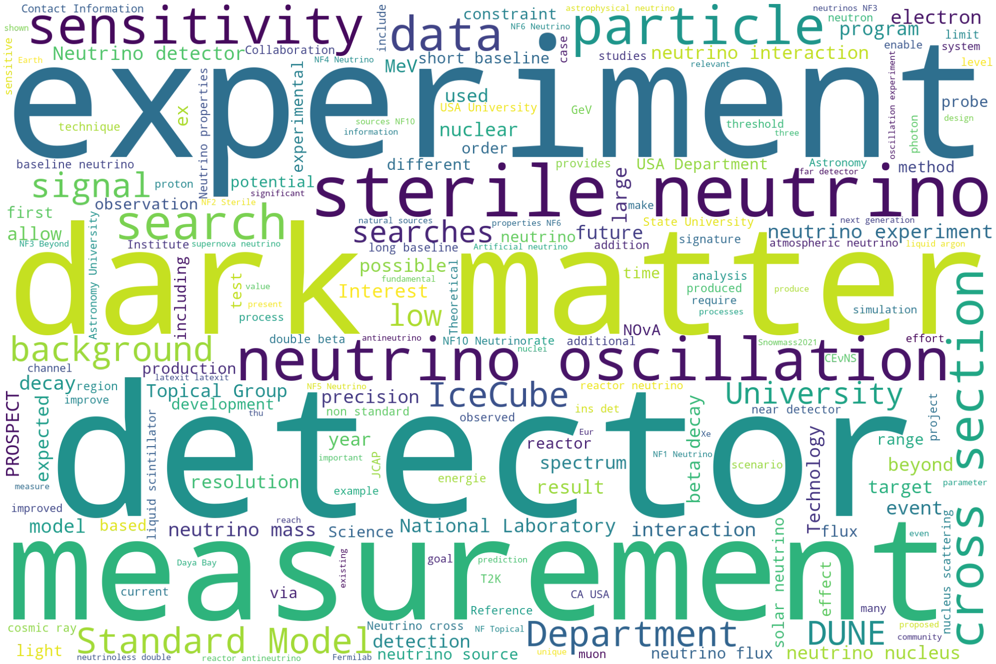
INTRODUCTION TO NEUTRINO FRONTIER



- NF01: Neutrino Oscillations
- NF02: Sterile Neutrinos
- NF03: BSM
- NF04: Neutrinos from Natural Sources
- NF05: Neutrino Properties
- NF06: Neutrino Interaction Cross Sections
- NF07: Applications
- NF08→TF11: Neutrino Theory
- NF09: Artificial Neutrino Sources
- NF10: Neutrino Detectors



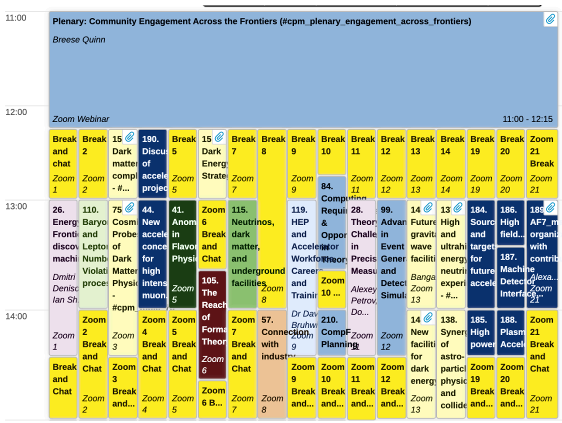
Word cloud by G. Watts
https://gordonwatts.github.io/snowmass-loi-words/

KEY QUESTIONS & DIRECTIONS FOR NEUTRINO FRONTIER

- Physics Topics:
  - Precision Neutrino Measurements
  - Physics Beyond the Standard Model
  - Neutrinos and the Cosmos
- Infrastructure/Tools:
  - Underground facilities
  - Detectors/Instrumentation/Sources
  - Event generators
  - Algorithms and computing
- Community Engagement
  - How can we improve the climate within our frontier (ethics, diversity, inclusion, career development)?
  - How can our frontier make contributions to society (education, public & political engagement, applications)?

GOALS FOR COMMUNITY PLANNING MEETING

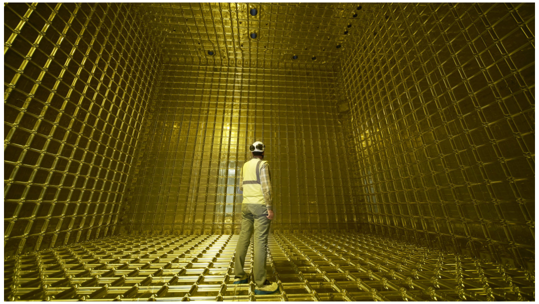
- This meeting focuses on the very big picture…
  - Broad overview of particle physics
  - Survey of strategies/plans in regions around the world
  - Community engagement across all frontiers
- And on very detailed cross-cutting issues
  - 14 sessions organized jointly between NF and other frontiers
  - Summaries of these in session 202: https://indico.fnal.gov/event/44870/sessions/16232/#20201007
- NF goals for CPM are to ensure:
  - Community input is effectively collected
  - **All cross cuts are identified and connections made**
  - **Required follow-up actions are identified**

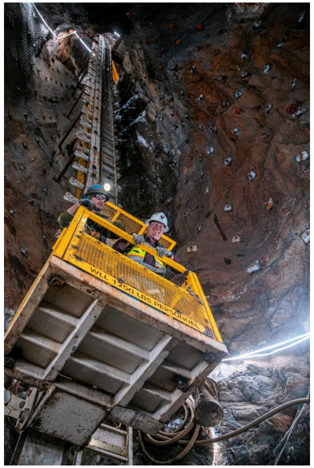


Note: because of the focus on cross-frontier issues, many high-priority items within the NF were not emphasized at this meeting. Many NF-specific topics are being discussed within NF topical group meetings and workshops.

PRECISION NEUTRINO MEASUREMENTS

- The primary physics goals of many neutrino experiments are precision measurements of neutrino oscillation parameters: Δm^2_{21}, Δm^2_{32}, θ_{12}, θ_{13}, θ_{23}, δ_{CP}
- Measurements of neutrino interactions and development of neutrino interaction models are essential for precision measurements and BSM searches involving neutrino detection
- The last Snowmass/P5 developed a plan for US-based precision neutrino oscillation measurements → DUNE
  - We are in the process of implementing this plan
  - Critical that full scope of previous P5 vision be realized
- Worldwide efforts also coming online in next decade
  - Complementarity, increased focus on combined analyses
- Fewer physics cross cuts, so less focus at this meeting
- Thoughts for next-next generation experiments starting to be discussed
  - See infrastructure sessions
- Similar story for neutrino mass measurements





NEUTRINOS & PHYSICS BEYOND THE STANDARD MODEL

- Neutrinos are the least accurately studied particles within the SM and thus can hide large-ish BSM signals
- Much of neutrino-related BSM is connected to dark sectors
- eV-scale sterile neutrino searches are being intensely pursued (less focus at this meeting)
- Neutrino sources typically are also neutral meson and photon sources → "neutral" BSM searches
- Neutrino detectors often useful for non-neutrino BSM searches
- Close relationship between theory and experiment needed to make progress

109	Determining the Masses and Nature of Neutrinos
126	BSM: direct and indirect searches
29	Low-energy precision experiments
97	Neutrinos as Probes of Standard and BSM Particle Physics
110	Baryon and Lepton Number Violating processes

BSM QUESTIONS

- Big Questions From CPM Sessions:
  - What is the nature and size of neutrino masses?
  - How do massive neutrinos impact the cosmic evolution?
  - Do neutrinos play a role in baryogenesis?
  - Are neutrinos a portal to the dark sector?

- Identified Cross Cuts:
  - $0\nu\beta\beta$ searches are a mainstay of neutrino physics
  - Measurements from asymmetries (n,p,e,molecular EDM) and neutrino interactions (CEvNS, CC) are ultimately related but quantitatively this has not yet been theoretically explored
  - Complementarity of CLFV and neutrino oscillation
  - Collider probes of low-scale neutrino mass generation

NEUTRINOS & ASTROPHYSICS/COSMOLOGY

- Neutrinos from astrophysical sources are probes of BSM physics
- Neutrinos are tools to learn about astrophysical objects, as a component of multi-messenger astronomy
- Properties of neutrinos are deeply entwined with cosmology
- Neutrino detectors can be used to search for dark matter, in multiple ways
- Dark matter instrumentation is also relevant for neutrino detection

108	Accelerator probes of light dark matter
109	Determining the Masses and Nature of the Neutrinos
77	Quantum sensors for wave and particle detection
127	Searches for dark sectors
51	Requirements for low background and underground detectors
97	Neutrinos as probes of standard and BSM particle physics
115	Neutrinos, dark matter and underground facilities
137	High and ultrahigh energy neutrino experiments

COSMIC QUESTIONS

- Big Questions From CPM Sessions:
  - What is the nature of dark matter? Are neutrinos a portal to the dark sector? Are sterile neutrinos DM?
  - How do massive neutrinos impact the cosmic evolution?
  - Do neutrinos play a role in baryogenesis?
  - Can we find signatures of new physics by observing astrophysical sources?
  - What is the nature of UHE neutrino production?
  - What is the core-collapse supernova explosion mechanism?
  - What can we learn from combining information with gravitational wave detectors, and from multi-messenger astronomy in general?
- Identified Cross Cuts:
  - Important to understand neutrino-nucleus interactions
  - Progress in instrumentation is needed to expand the range of sensitivity
  - Obvious overlap with CF physics

INFRASTRUCTURE/TOOLS

- Frameworks for theoretical calculations and implementation of models (ie: generators) are critical tools
- Neutrino experiments are becoming increasingly computing intensive
  - Large datasets, significant computing resources needed for simulation, implementation of machine learning algorithms, systematics evaluation
- Neutrinos cross-sections are very small: precision measurements and discovery potential require powerful neutrino sources, massive detectors, attention to reducing background
- Significant overlap in detector technology and underground facility needs among dark matter, $0\nu\beta\beta$, and neutrino oscillation experiments
- Advanced detectors/sensors being developed for next-next generation experiments

124	Lattice Gauge Theory for High Energy Physics
61	Energy, Power, and Time Structure Goals for NF Programs
77	Quantum sensors for wave and particle detection
81	Neutrinos and Computing: Preservation, Machine Learning, Uncertainties
51	Requirements for low background and underground detectors
115	Neutrinos, dark matter and underground facilities
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INFRASTRUCTURE/TOOLS QUESTIONS

- Questions From CPM Sessions:
  - How low can noise characteristics of detector systems be pushed using quantum sensors? How can we deploy quantum sensors in mid-scale experiments?
  - Computing tradeoffs between "ease of use" and agility? Successful examples to follow for data preservation and reanalysis? New ways to think about systematics analysis to better use resources?
  - What is the best way to pursue large multi-purpose (DM, $0\nu\beta\beta$, neutrinos) experiments? How to handle stovepiping?
  - What is the status of detector technologies being considered for UHE neutrinos and what physics topics do these facilitate?

- Identified Cross Cuts:
  - Describing neutrino-nucleus scattering from the Standard Model requires control of QCD over a wide range of scales and physics processes
  - AF would like input on requirements for beam details (intensity, energy, timing, etc) for neutrino experiments
  - Gravitational wave detectors and experiments using atomic techniques have complementary technology challenges in quantum sensing; significant overlap with IF in detectors/sensors/etc
  - Desire expressed for underground facilities to coordinate with the physics community and among the labs, to facilitate multiple scales of experiments, and to support full realization of US-based facility at SURF. Additional sites at SURF and SNOLAB being explored for future

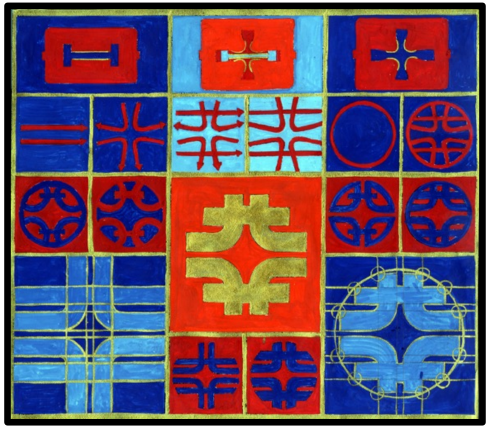
FOLLOW UP ACTIONS IDENTIFIED

108	Accelerator probes of light dark matter	Theory/pheno/expt coordination for development of standardized plots, tools, data releases, studies; LDM white paper across frontiers
109	Determining the Masses and Nature of the Neutrinos	4 specific white papers identified, dedicated workshop planned
77	Quantum sensors for wave and particle detection	Want theory effort for guidance, define common infrastructure needs (TF, IF)
51	Requirements for low background and underground detectors	Planned workshop on beyond-ton-scale $0\nu\beta\beta$; planned further discussion/whitepaper on future multipurpose facility
97	Neutrinos as probes of standard and BSM particle physics	Collaboration with computing, theory needed; neutrino-nucleus interaction measurements needed

FOLLOW UP ACTIONS IDENTIFIED (CONT.)

115	Neutrinos, dark matter and underground facilities	Community and lab coordination needed; ongoing support for 4 DUNE modules + smaller projects needed
137	High and ultrahigh energy neutrino experiments	2-3 white papers, workshops coordinating with CF, TF, IF
29	Low-energy precision experiments	Dedicated theory workshop
110	Baryon and Lepton Number Violating processes	Plan for coordinated white papers developing
61	Energy, Power, and Time Structure Goals for NF Programs	Identified white papers to solicit, provide requested input to AF
81	Neutrinos and Computing: Preservation, Machine Learning, Uncertainties	Identified specific follow-up questions

COMMUNITY ENGAGEMENT



- The neutrino frontier embraces our obligations to our colleagues and to society at large
- NF early-career physicists have been very active in SEC leadership and are fully embedded in NF activities
- NF has a topical group for Applications
- Many institutions central to NF (including Fermilab and SURF) have active social media, community outreach, environmental awareness, site tours, cultural, and education programs in place
  - How can we better communicate with communities who don't seek us out?
  - Are we making sure to be good citizens of the communities where we build our experiments?
- We all have work to do on justice, inclusion, and diversity - we are learning, listening, organizing, and trying to do better: particlesforjustice.org is a great resource

NEXT STEPS FOR NEUTRINO FRONTIER

- Whitepaper Planning:
  - Goal is to identify white paper topics that provide important additional input to Snowmass/P5
  - No need to reproduce existing documentation – focus on cross cuts and new ideas!
  - A number of white paper topics have already been identified during the LOI and CPM processes
  - Expect a NF white paper kickoff workshop in Nov/Dec 2020
- Other Neutrino Frontier Activities:
  - Topical group workshops ongoing (summer 2020 – spring 2021)
  - Planned special topics workshops (often joint with other frontiers)
  - Neutrino Frontier Workshop March 15-17, 2021, hosted by ORNL (likely remote)
  - Focus on early drafts of NF report to encourage dialogue/feedback

Questions?
Comments?